Le défi de l'intégration des ressources renouvelables distribuées dans les réseaux électriques

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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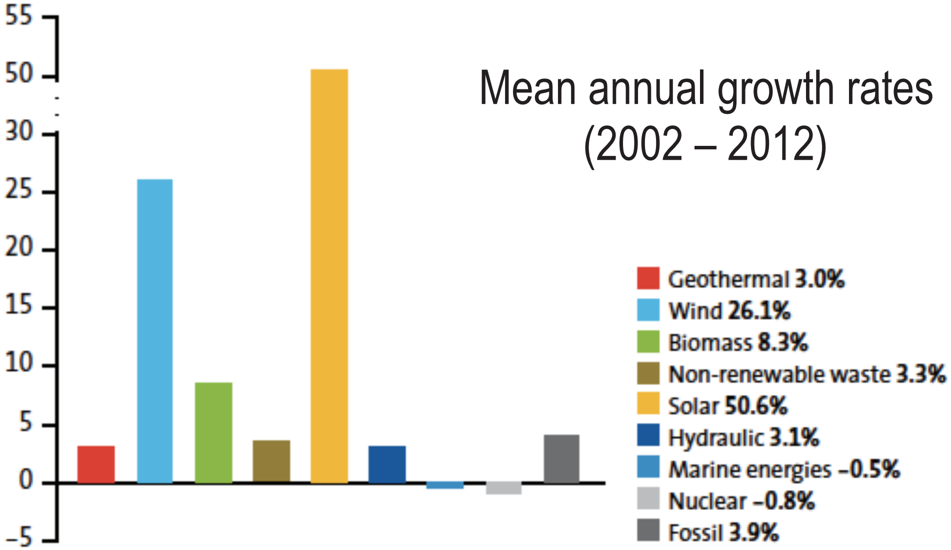
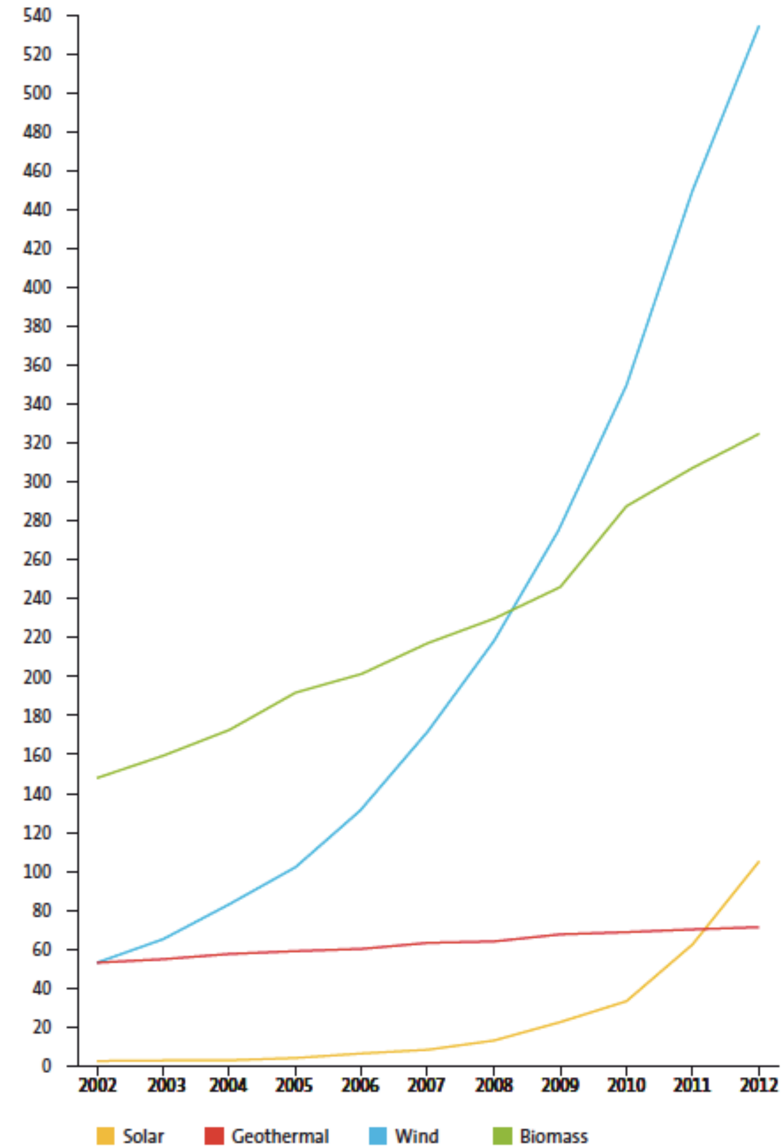
Outline

The Drivers

The worldwide response in terms of **increase of renewables for the production of electricity**

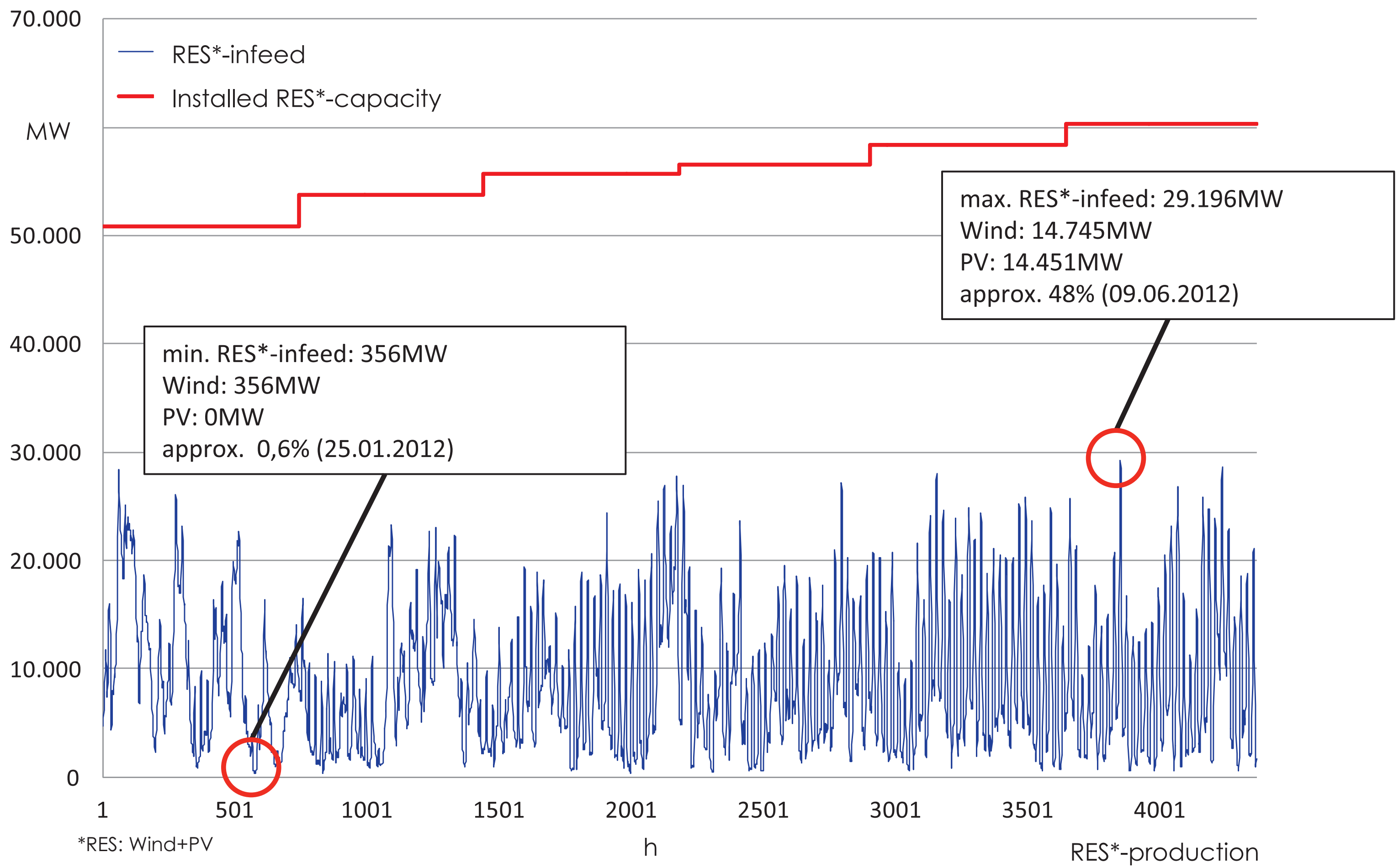




Source: 15[5h] inventory of of worldwide electricity production from renewable energy resources. 2013.

The Drivers

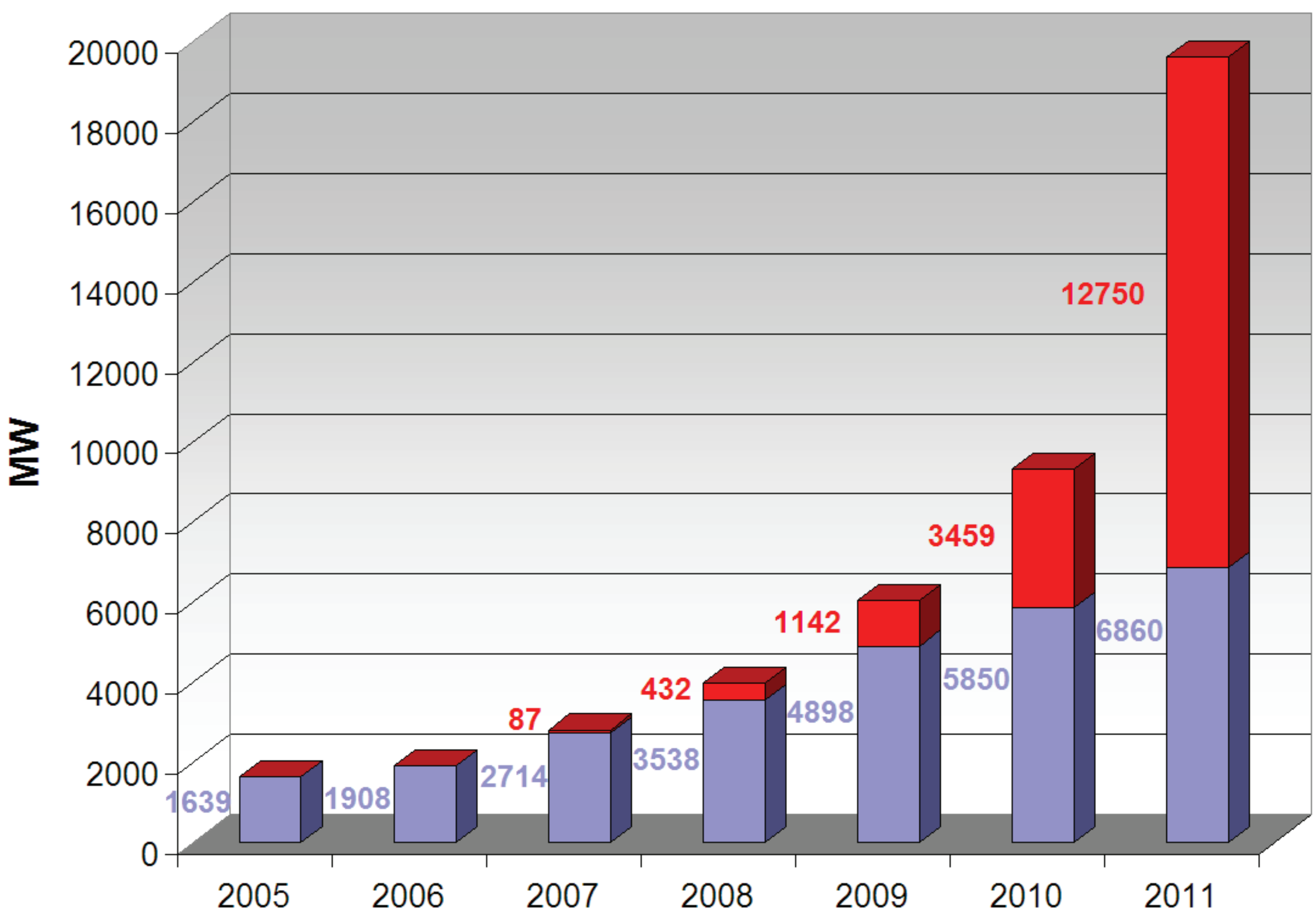
Seasonal volatility (Wind+PV)
Installed capacity vs real infeed: the case of Germany



*RES: Wind+PV

The Drivers

Grow rate of decentralized energy resources: the case of Italy



In **April 2013**, the **PV** installed capacity has reached **16.5 GWp**

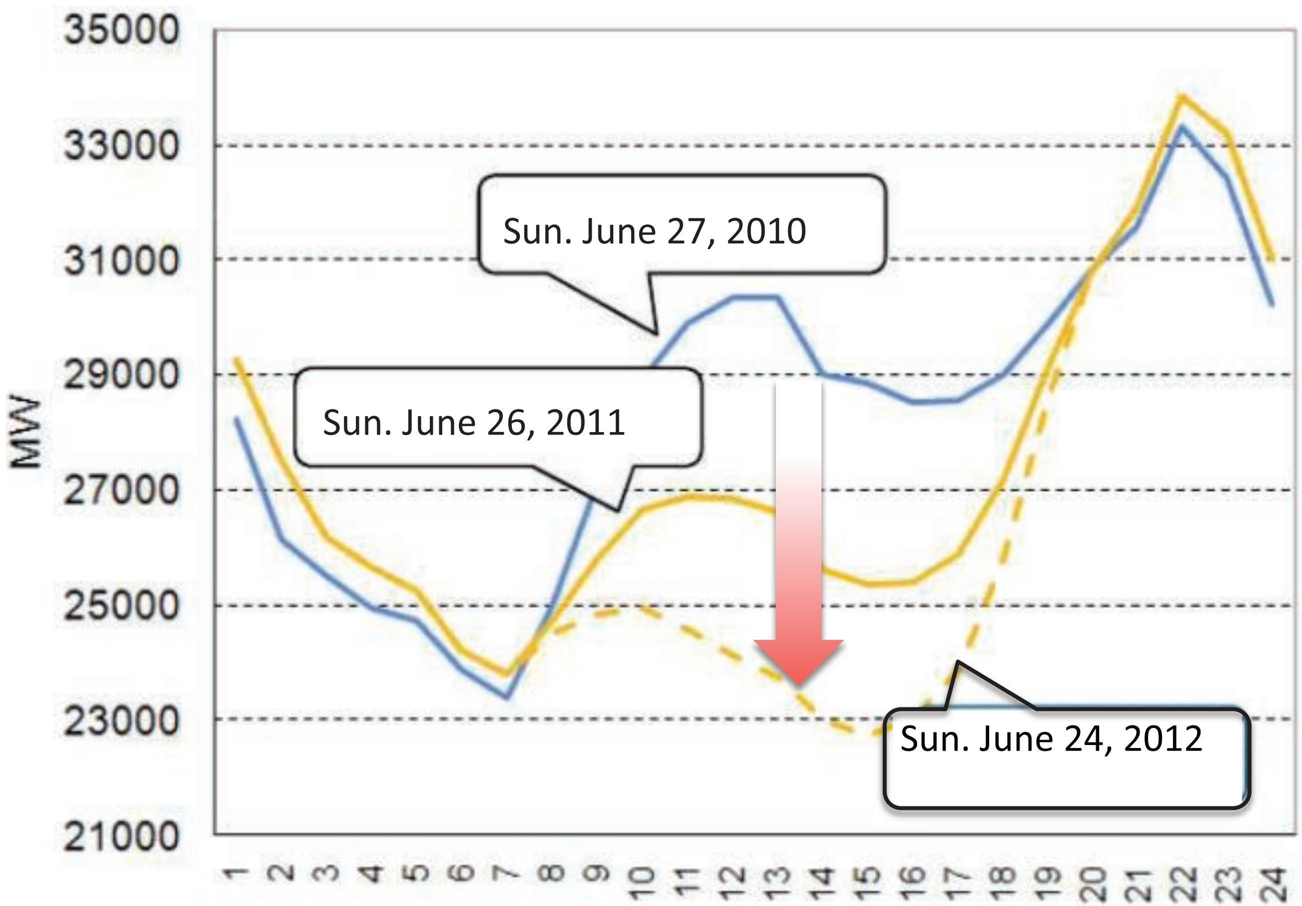
Energy prod:
2011: 10.7 TWh
2012: 18.8 TWh
½ 2013: 13.8 TWh (7.3% of the demand)

PV
Wind

The Drivers

Impact on the daily load curve: the case of Italy

Remark#1: possibility to have phases along the day with large reduction of the net power flow on the transmission network.

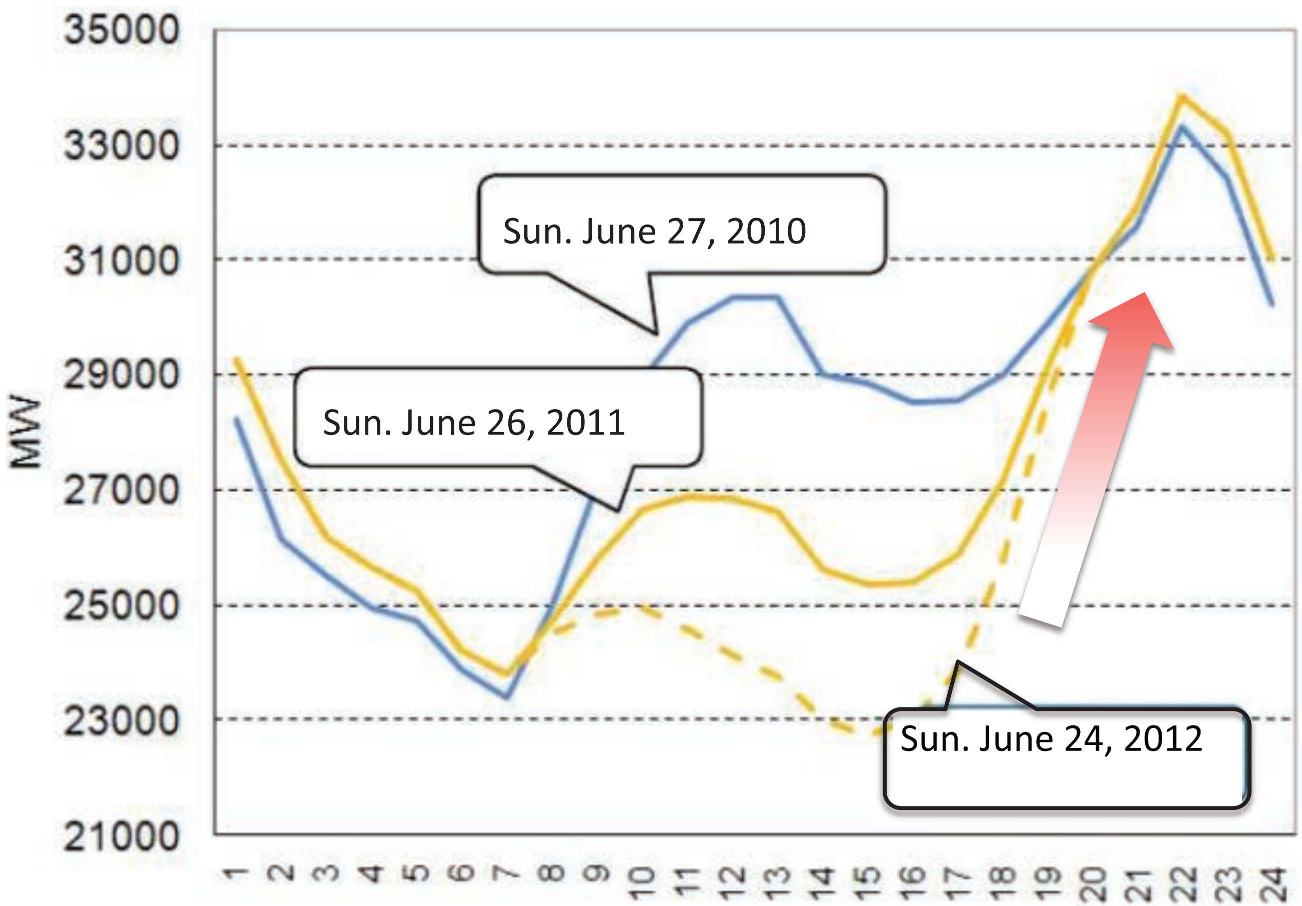


Source: Terna S.p.A.

The Drivers

Impact on the daily load curve: the case of Italy

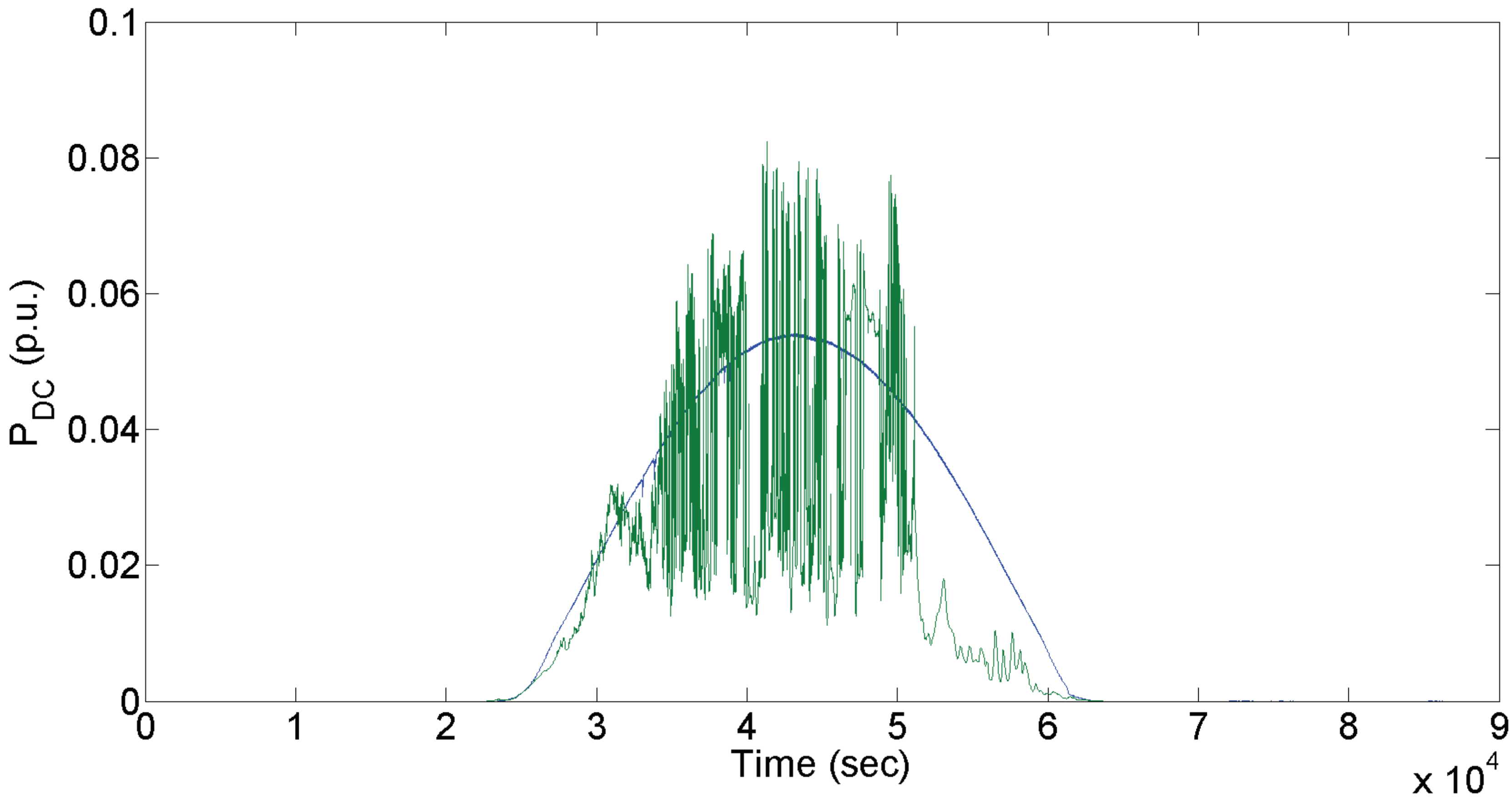
Remark#2: need of faster ramping in the evening hours



Source: Terna S.p.A.

The Drivers

Short-term volatility (PV)
Example of daily measured power injected by solar arrays at EPFL



The Drivers

Short-term volatility (PV)

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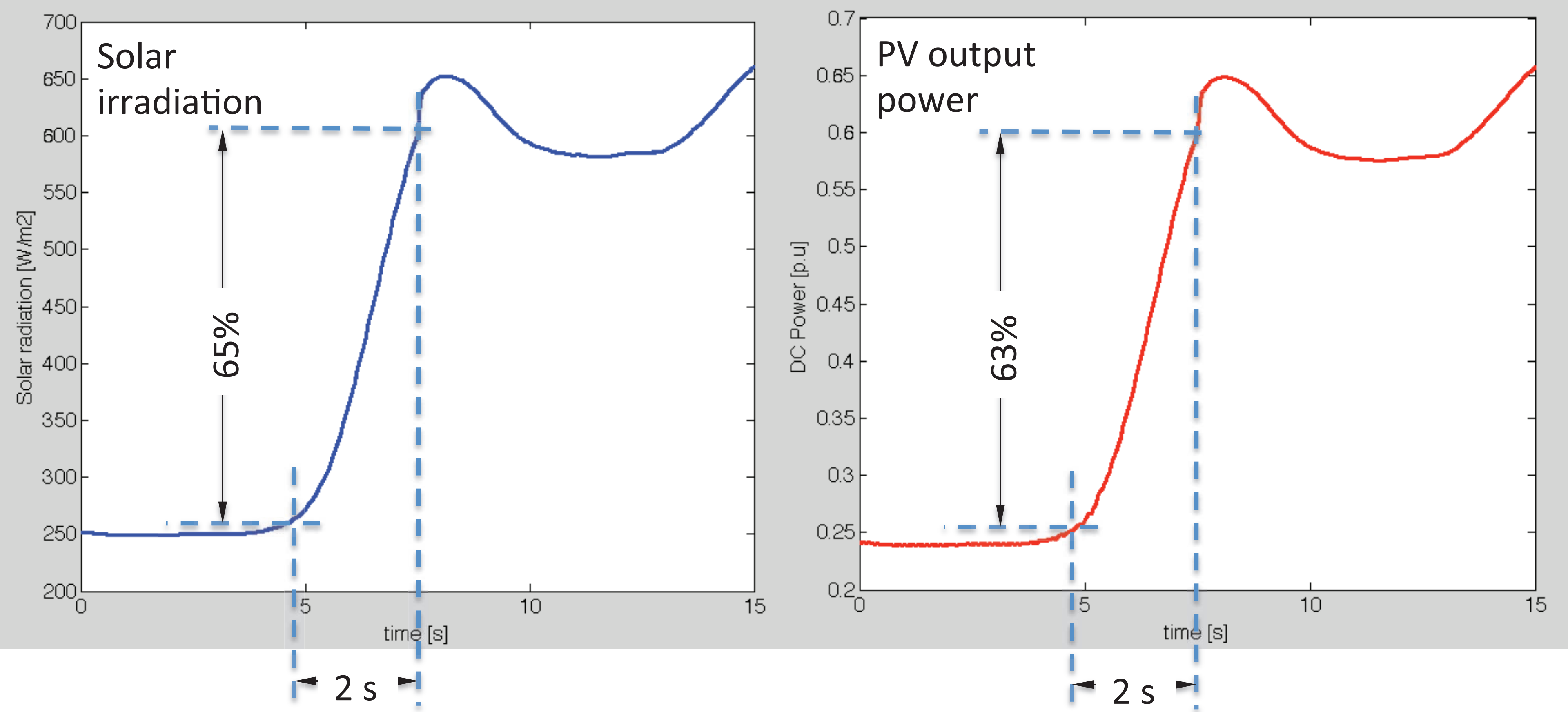
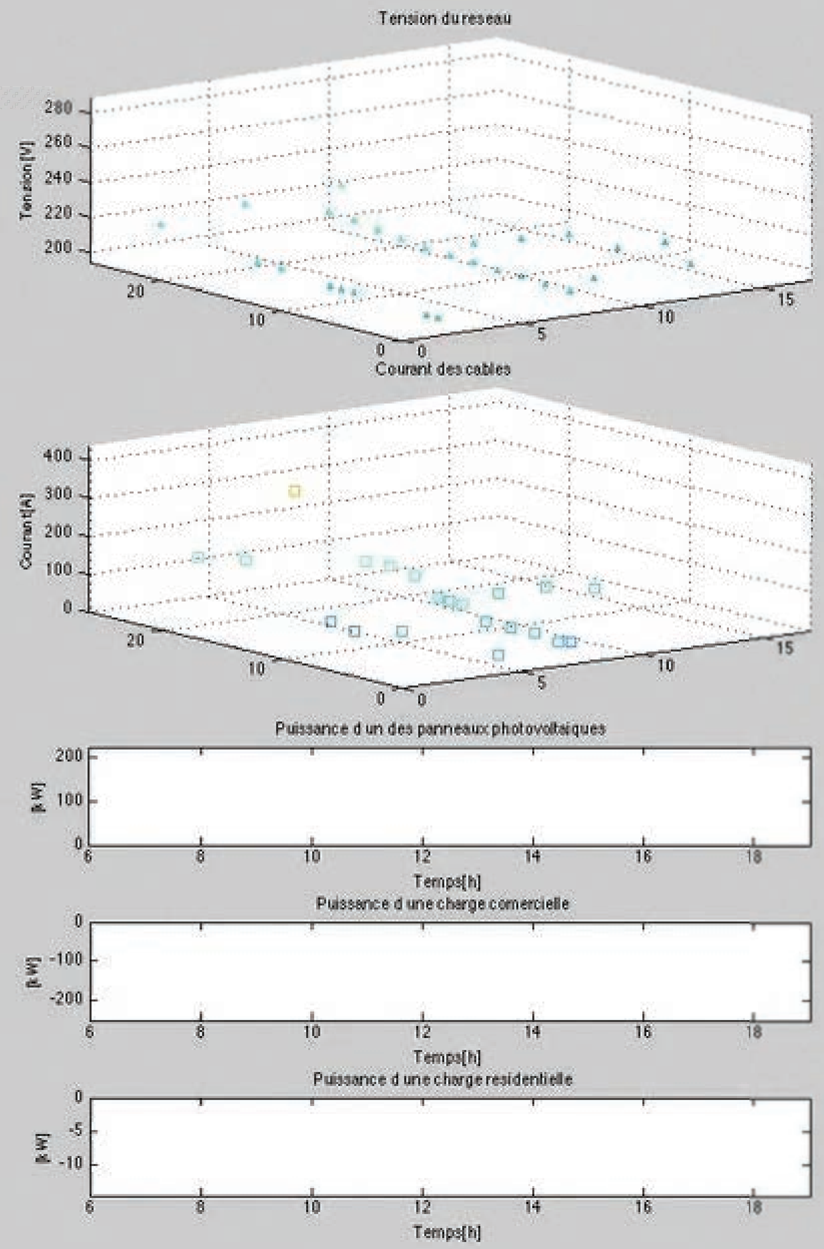
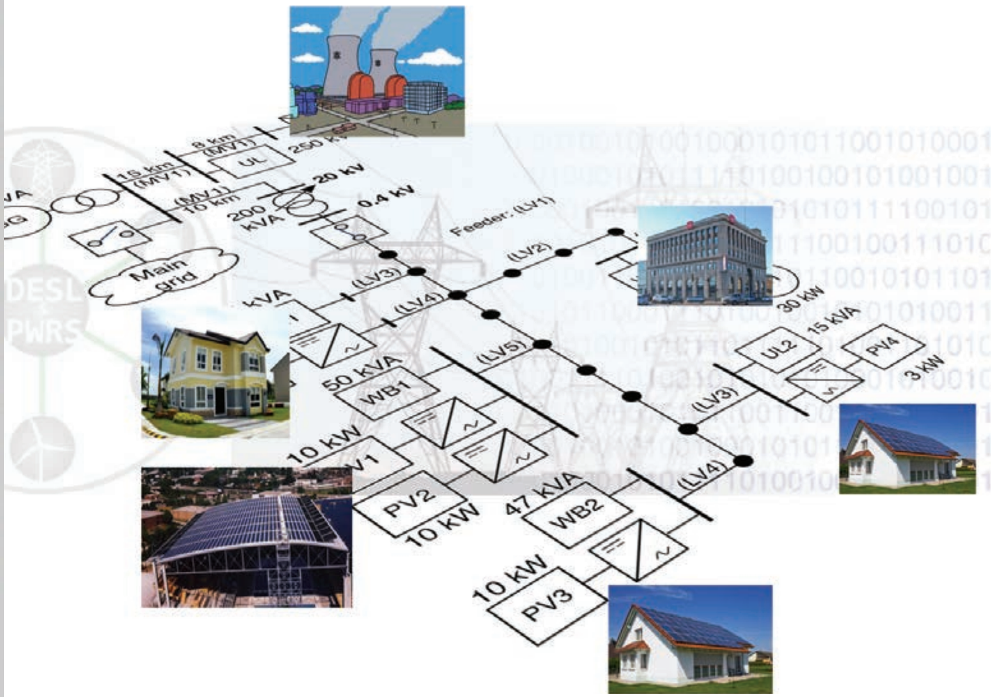


Impact of renewables short-term volatility on the quality of service of the grid

- Voltage and line amapcity
- Volatility = difficult control (optimal)





Outline

The Challenges

Challenges for grids

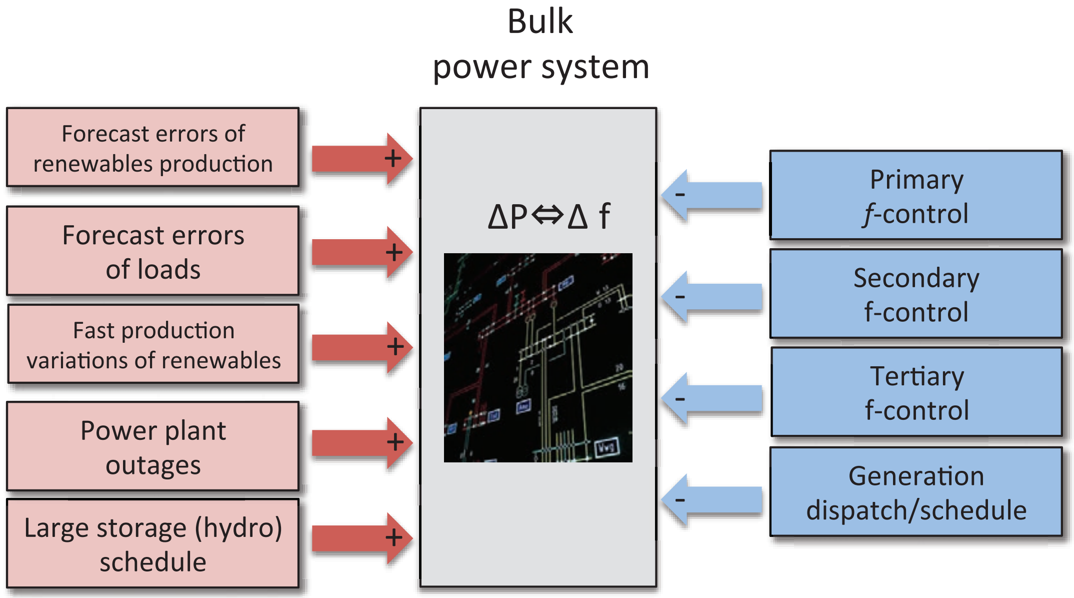
- quality of service in distribution networks;
- participation of distributed generation to frequency and voltage support *(Virtual Power Plant)*
- autonomous small scale grids with little inertia

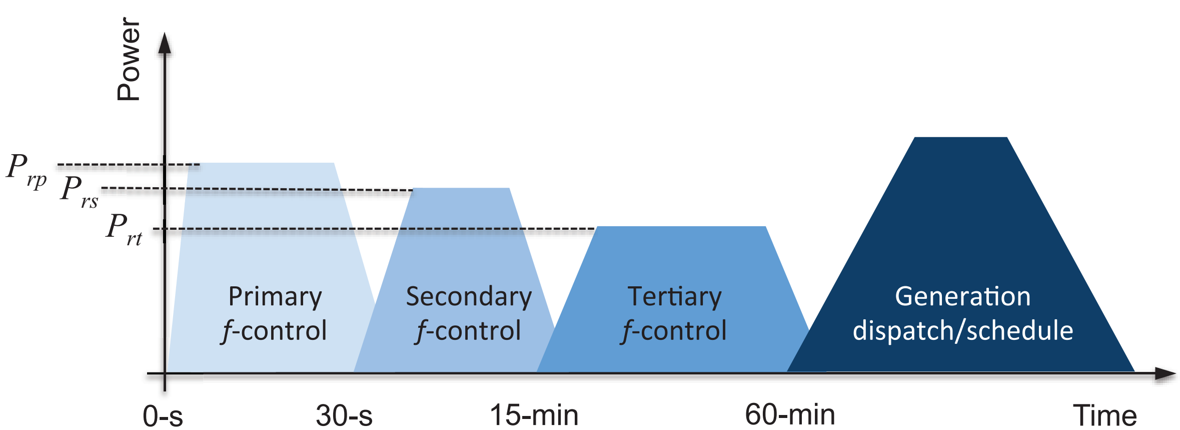
Solutions

- fast ramping generation (fossil fuel based)
- local storage, demand response
- *real time control* of local grids

The Challenges

Optimal and robust control of bulk systems with high-volatile resources





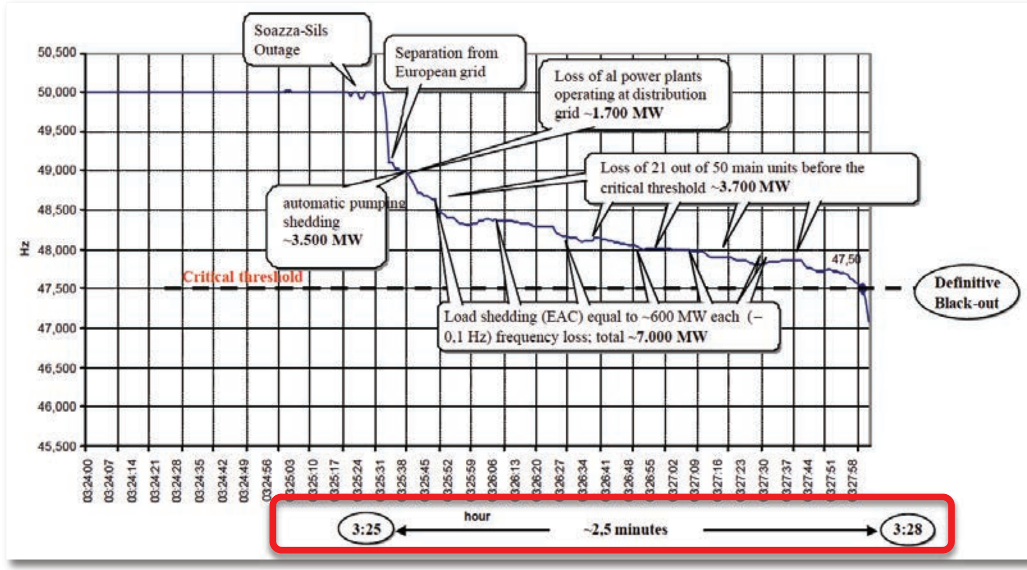
Main challenges: can we still use this approach to control systems with major penetration of stochastic resources ?

The Challenges

Towards inertia-less systems ?

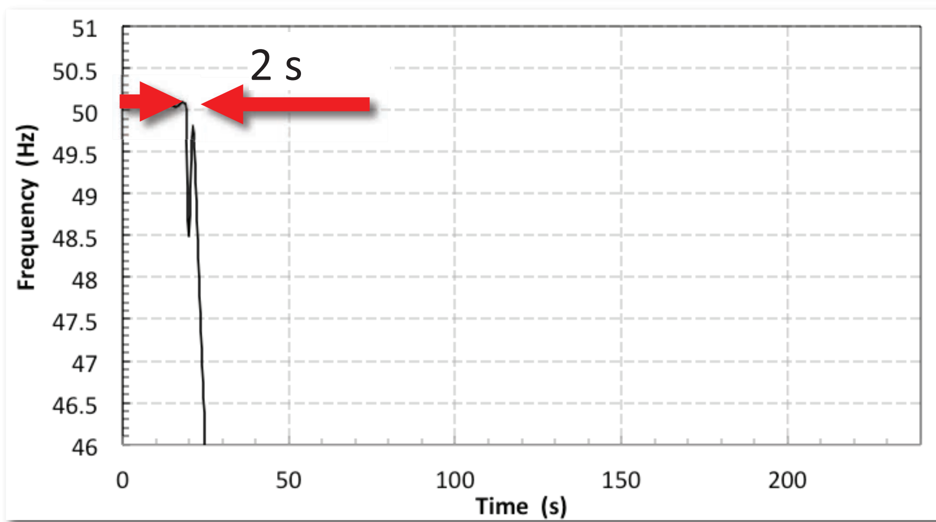
2003 blackout in Italy frequency trend

Source: UCTE Interim Report of the Investigation Committee on the 28 September 2003 Blackout in Italy



2009 blackout during the islanding maneuver of an active distribution network

Source: A. Borghetti, C. A. Nucci, M. Paolone, G. Ciappi, A. Solari, "Synchronized Phasors Monitoring During the Islanding Maneuver of an Active Distribution Network", IEEE Trans. On Smart Grid, vol. 2 , issue: 1, march, 2011, pp: 70 – 79.



The Challenges

Optimal and robust control of bulk systems with high-volatile resources

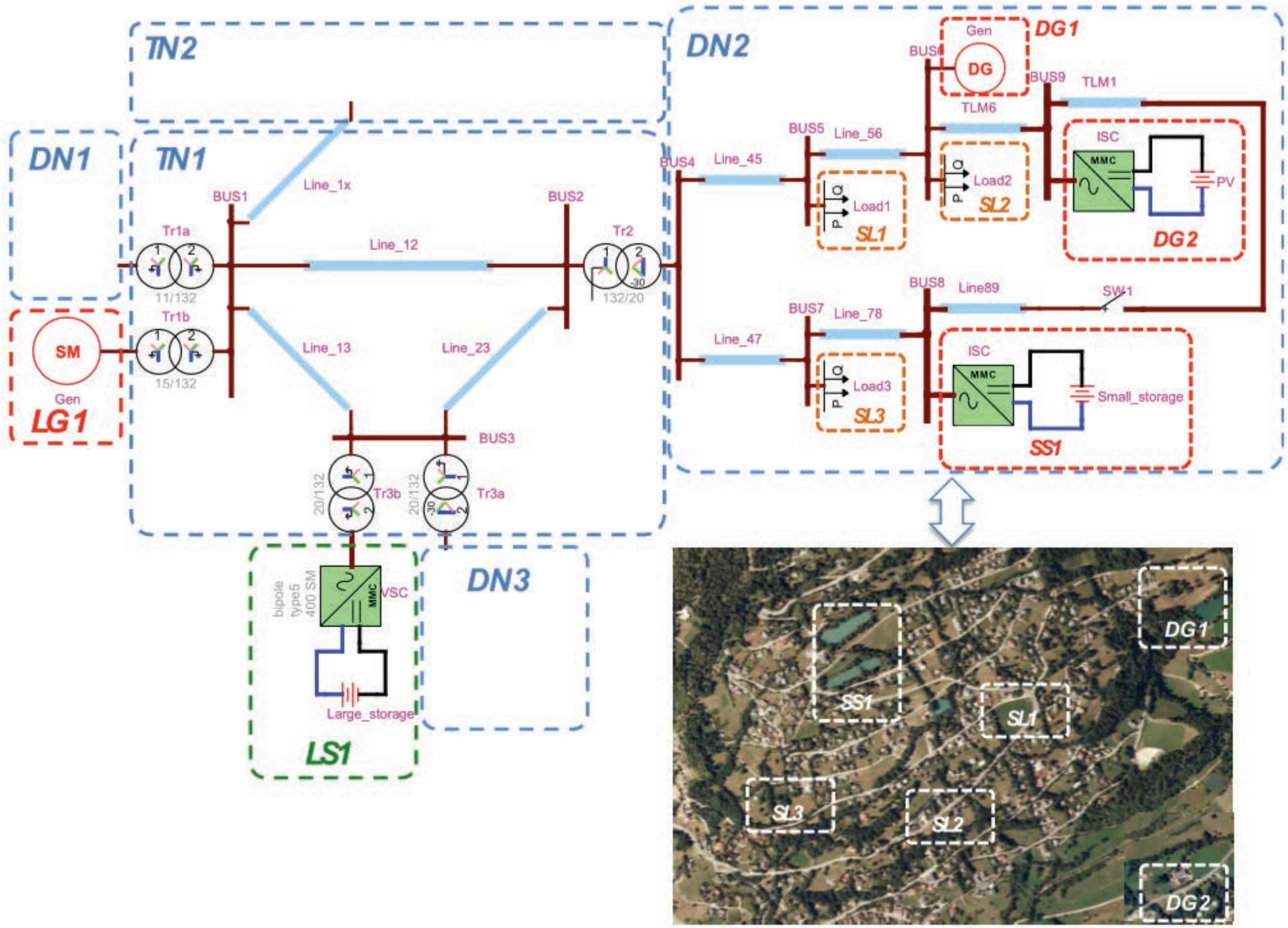
- Typically done with droop controllers on main power plants
- Problems:
  - system does not know the state of resources (e.g. temperature in a building, state of charge in a battery)
  - all problems made global
- Alternative: *optimal explicit control of power setpoints*
  - *mathematically complex*
  - *radical change in grid operation*

Outline

The COMMELEC Protocol

The COMMELEC idea

Optimal and robust control of bulk systems with high-volatile resources

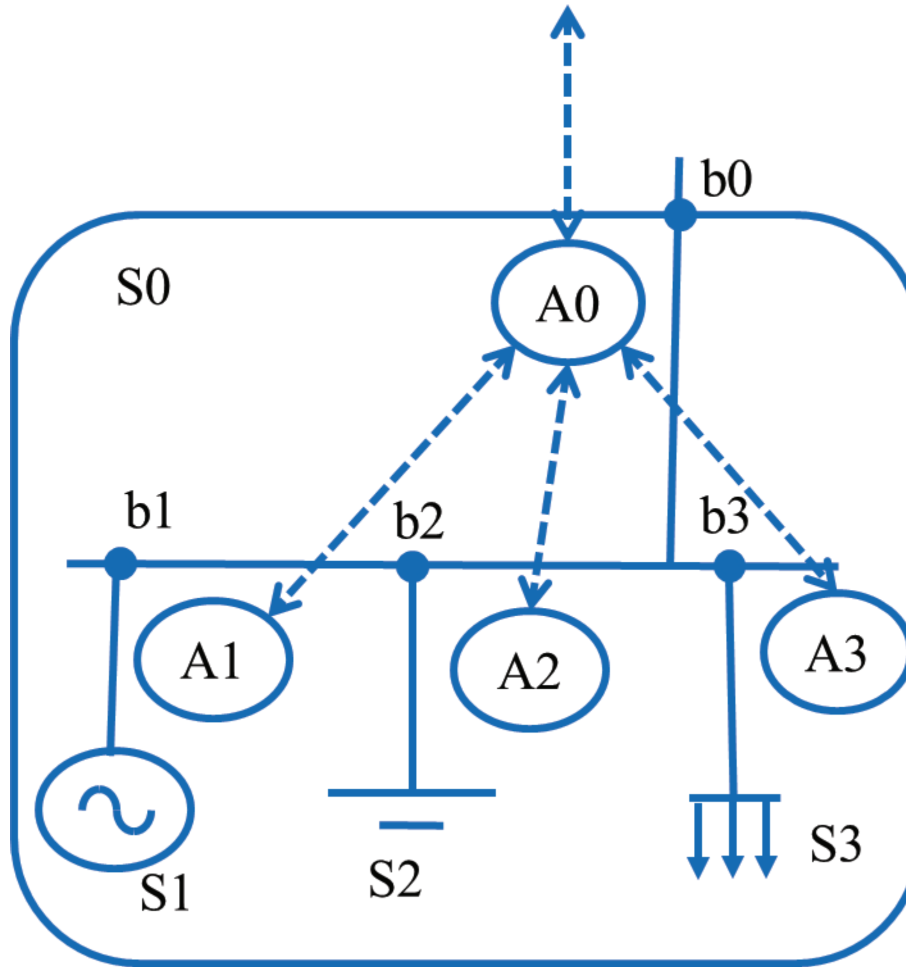


1. Real time
2. Bug free
   (i.e. simple)
3. Scalable
4. Composable
   e.g. TN1 can control DN2; DN2 can control SS1

COMMELEC's Architecture

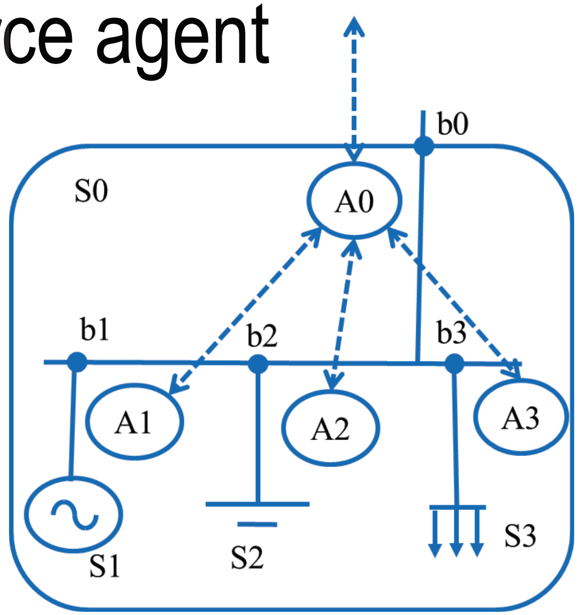
- **Software Agents** associated with devices
  - load, generators, storage
  - grids

- **Grid agent sends** explicit ***power setpoints*** to devices' agents

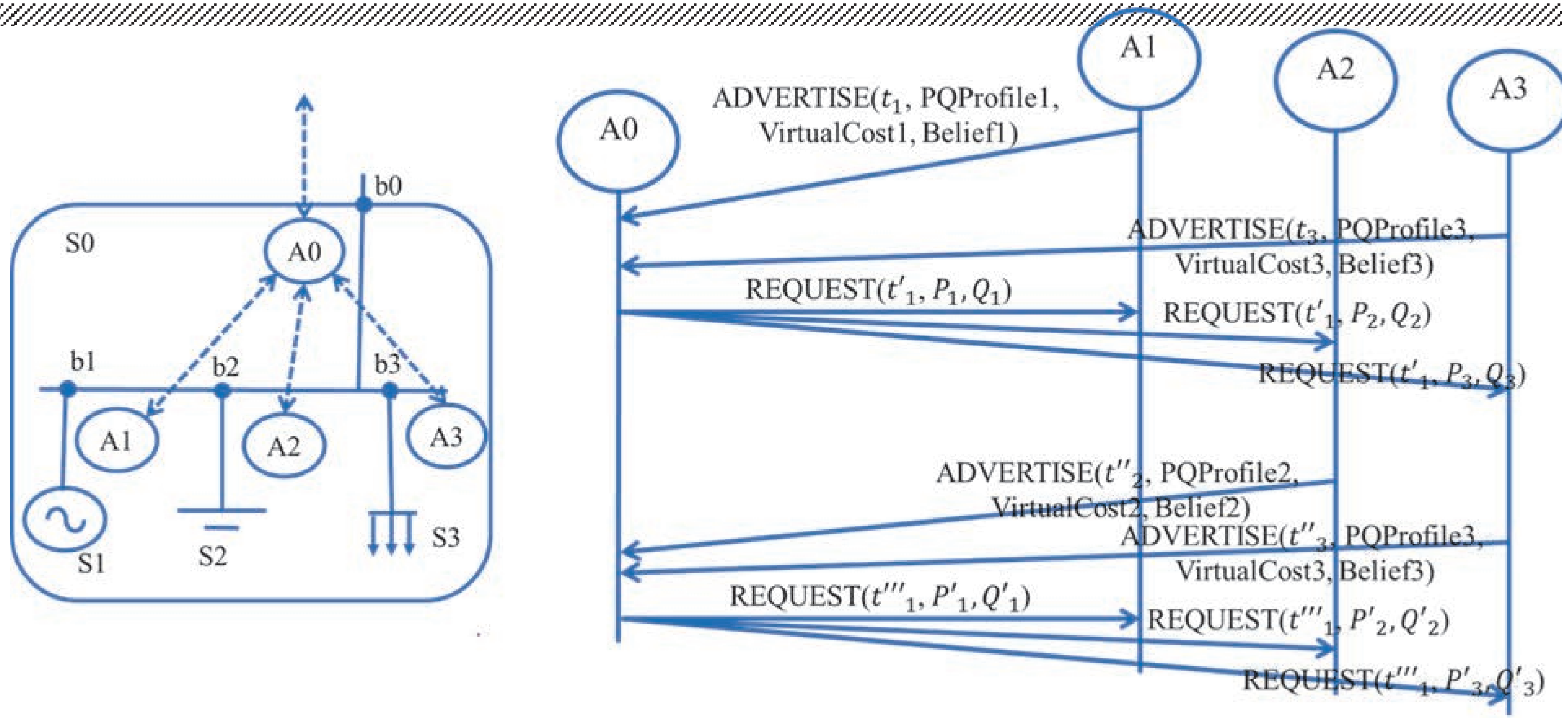


COMMELEC's Architecture – Resources and Agents

- Resources can be
  - controllable (sync generator, battery)
  - partially controllable (PVs, boilers, HVAC, TCLs)
  - uncontrollable (load)
- Each resource is assigned to a resource agent
- Each grid is assigned to a grid agent
- Leader and follower
  - resource agent is follower or grid agent
  - LV grid agent is follower of MV agent



COMMELEC's Architecture – The Protocol

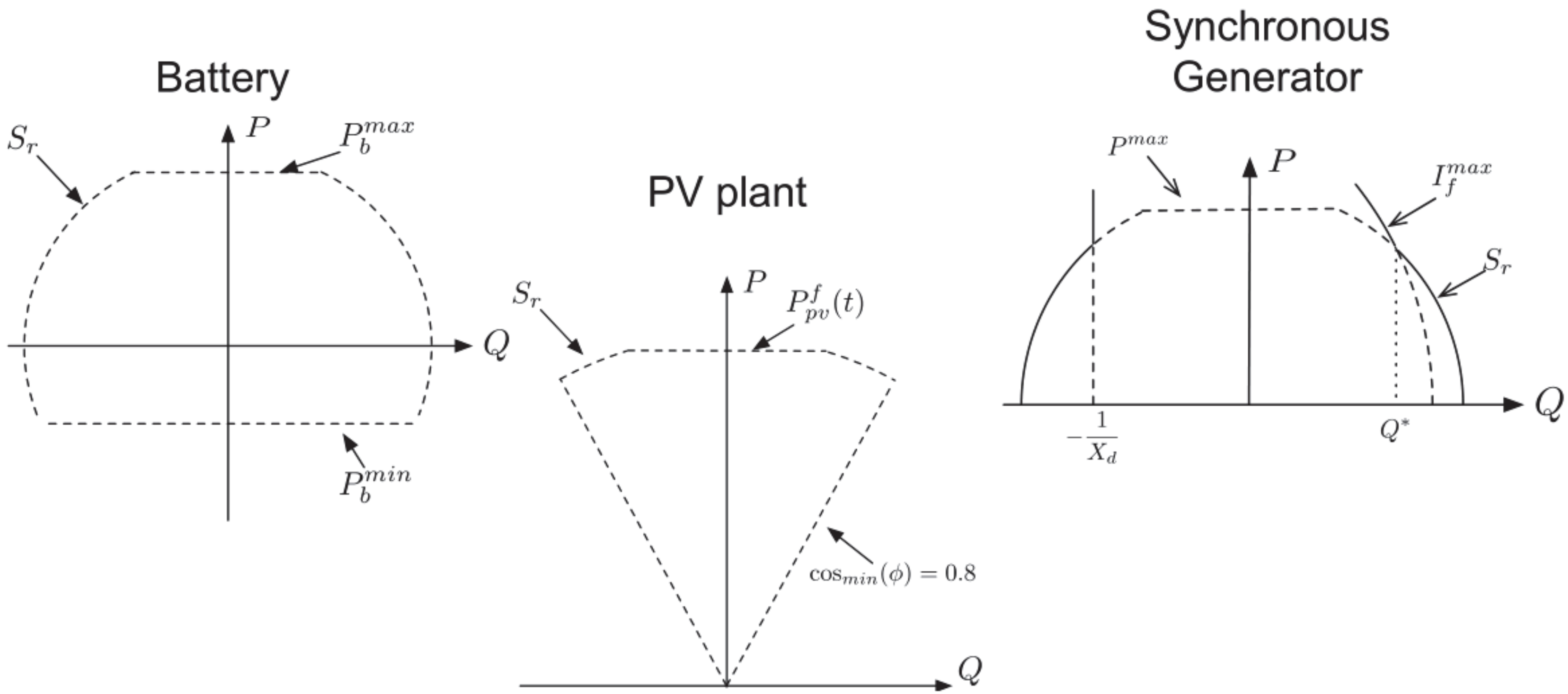


- Every agent advertises its state (example each 100 ms) as a ***PQt profile***, a ***virtual cost*** and a ***belief function***
- Each Grid agent computes optimal setpoints and sends them as requests to resource agents.

COMMELEC's Architecture – The PQt Profile

PQt profile as a system of coordinates for any resource connected to the grid.

Examples of PQt profiles



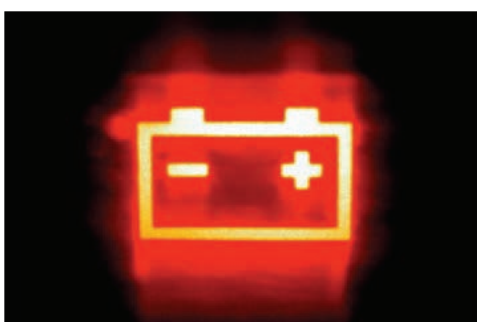
COMMELEC's Architecture – The Virtual Cost

Virtual cost acting as proxy for the *resource internal constraints*

I can do P,Q in the next t
It cost you (virtually) $C(P,Q)$
Example:
If (State-of-Charge) is 0.7
I am willing to inject power

If (State-of-Charge) is 0.3,
I am interested in absorbing power

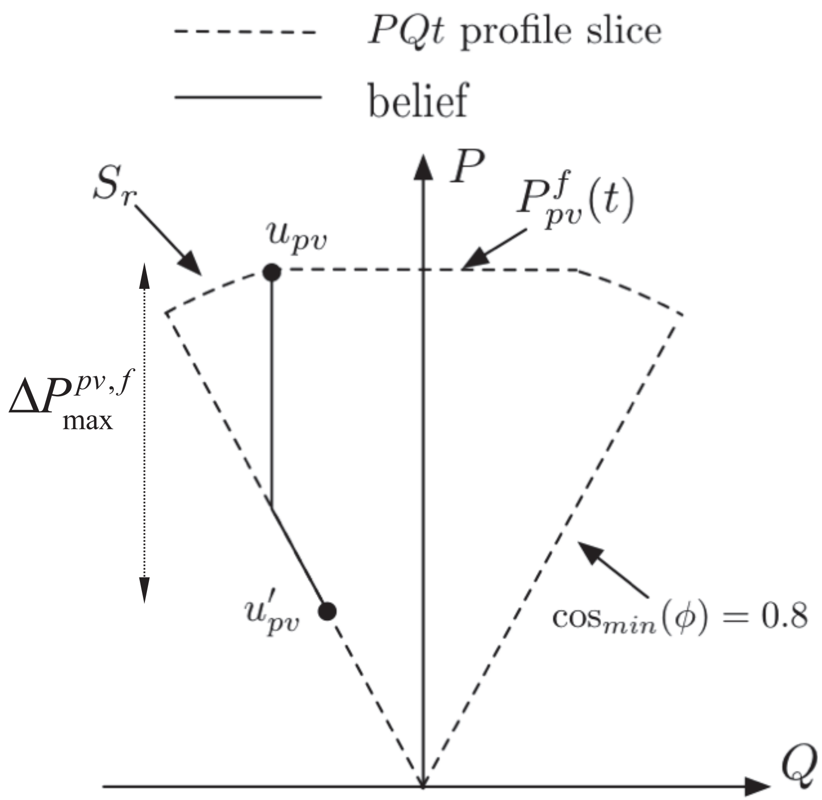
Battery agent



Grid agent

COMMELEC's Architecture – The Belief Function

- Say grid agent requests setpoint (P_{set}, Q_{set}) from a resource
- Actual setpoint (P, Q) **will, in general, differ**
- The ***belief function*** is exported by a resource agent with the semantic: resource implements $(P,Q) \in BF(P_{set}, Q_{set})$
- It gives bounds on the actual (P,Q) that will be observed when the follower is instructed to implement a given setpoint.
- Essential for safe operation.



COMMELEC's Architecture – The Grid Agent's Job

- **Leader agent (grid agent)** computes setpoints for followers based on
  - the state of the grid
  - advertisements received from the resources

- The Grid Agent attempts to minimize

$$J(x) = \sum_i C(x_i) + W(z)$$

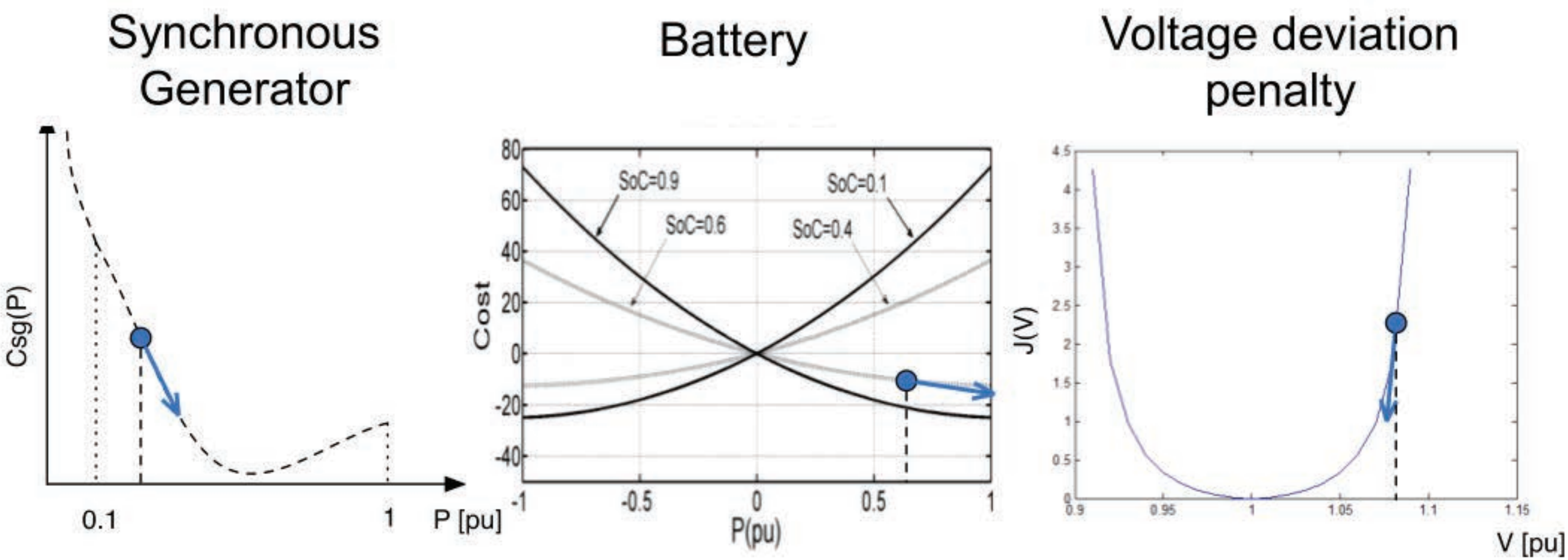
Virtual cost of the resources

Penalty function of grid electrical state z (e.g., voltages close to 1 p.u., line currents below the ampacity)

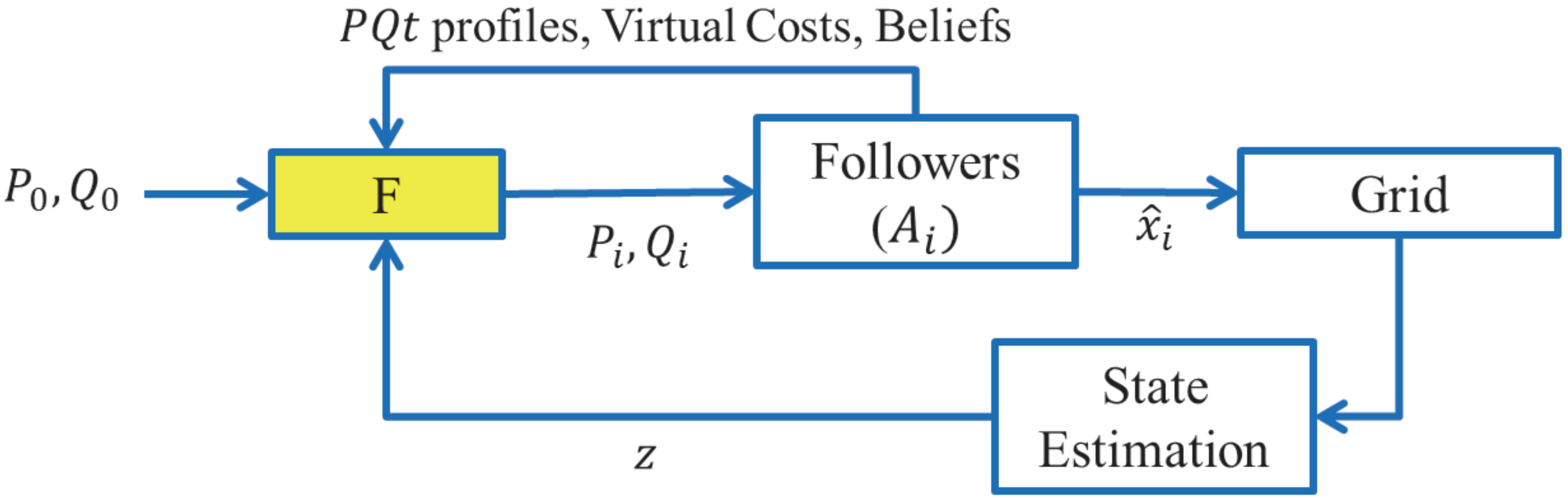
- The Grid Agent **does not see the details of resources**
  - a grid is a collection of devices that export PQt profiles, virtual costs and belief functions and has some penalty function
  - problem solved by grid agent **is always the same**

COMMELEC's Architecture – The Grid Agent's Job

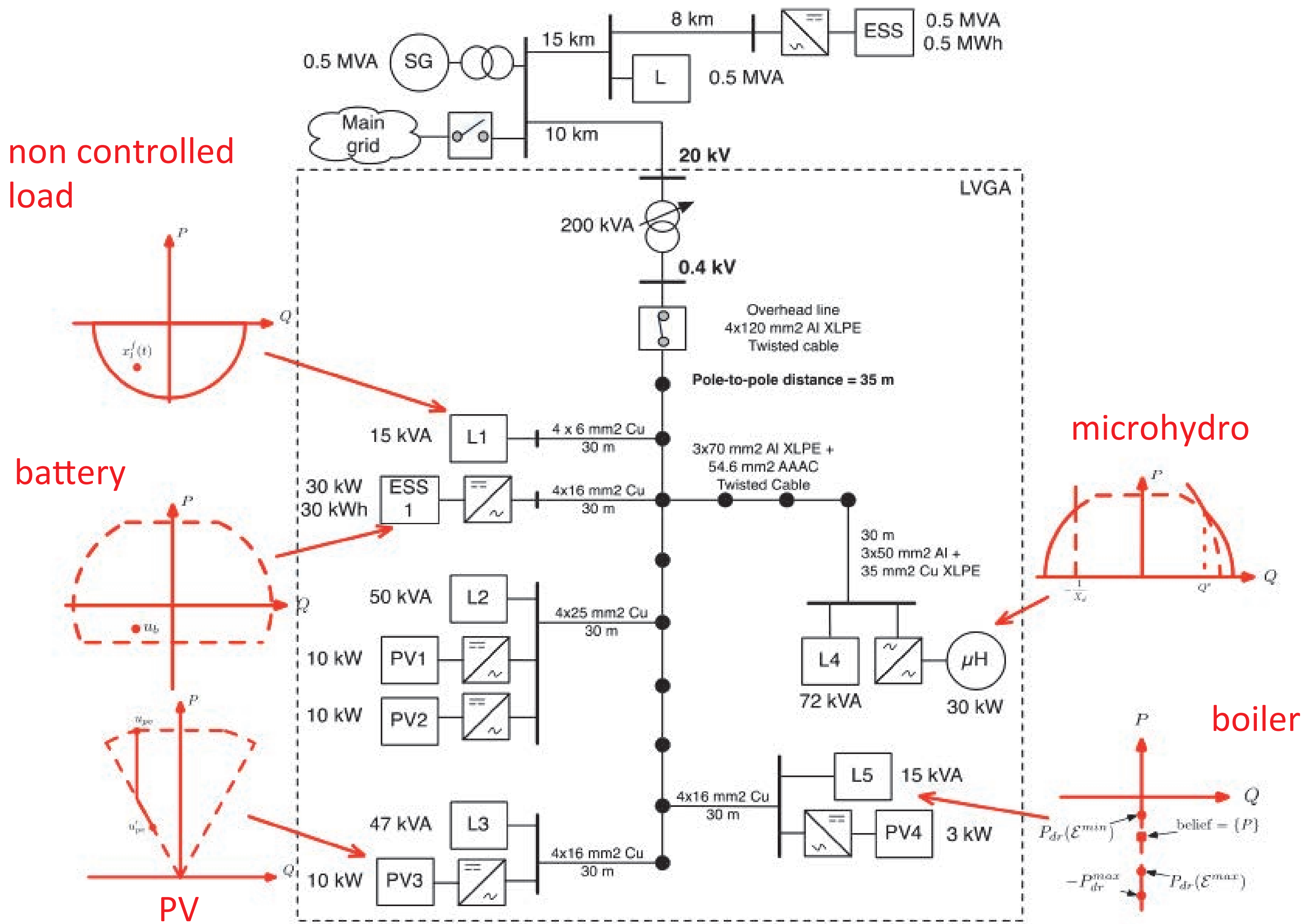
Setpoint Computation by Grid Agent involves gradient of overall objective = sum of virtual costs + penalty



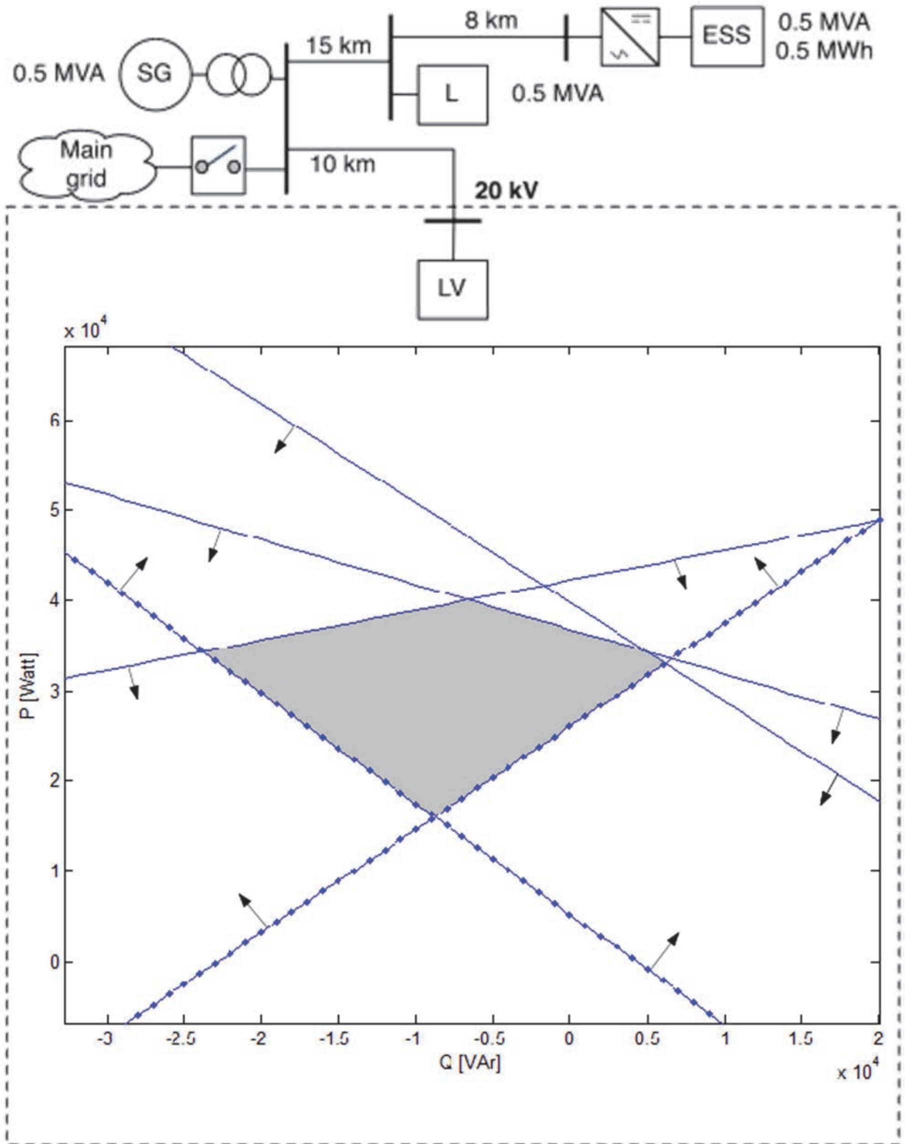
COMMELEC's Architecture – The Grid Agent's Job



COMMELEC's Architecture – Aggregation, Composability



COMMELEC's Architecture – Aggregation, Composability



Aggregated *PQt* profile

safe approximation (*subset* of true aggregated *PQt* profile)

COMMELEC's Architecture – The Grid Agent's Job

- **Observe** and **estimate the state** of the grid;
- Compute the **safe state of the grid**
- Compute **optimal setpoints** to be forwarded to the **resource agents** to steer the electrical state of the grid to:
  - Minimize the cost of the followers
  - Satisfy the leader's request as much as possible
  - Maintain the grid in a safe state of operation

COMMELEC's Architecture – The Grid Agent's Job

Observe and **estimate the state** of the grid;